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# ENHANCEMENT OF EXIT89 AND ANALYSIS OF WORLD TRADE CENTER DATA



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Technology Administration
National Institute of Standards and Technology

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Notice

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# Enhancement of EXIT89 and Analysis of World Trade Center Data

**Final Report**

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# Final Report on Grant No. 60NANB4D1584
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## Introduction

This grant had two separate tracks -- continued refinement of EXIT89 and analyses of the World Trade Center human behavior study data collected under earlier NIST grants (Order No. 43NANB319578 and Grant No. 60NANB2D1286).

The additional features added to EXIT89 will be described in this paper. A users manual for EXIT89 was also developed and a NISTIR co-authored by Daniel Alvord of NIST describing the use of EXIT89 and comparisons with EXITT is almost complete.

The World Trade Center human behavior study questionnaire was developed and mailed out under one earlier grant and a coding manual was developed for the analysis phase of the project under another grant. This grant covered the analysis of survey responses.

This final report will document the work completed under the grant. It is not the purpose of this paper to describe EXIT89, as that has been done in other papers.[1] Similarly, the World Trade Center incident is not described here, nor is the development of the survey questionnaire.

## EXIT89 Enhancements

At the beginning of the grant period, EXIT89 had the following capabilities: 1) it could handle the evacuation of up to 700 occupants in 308 locations; 2) the user could specify the measurement units used for input and output, the average size of occupants, whether they travel at "normal" or "emergency" speeds; whether they follow directed or shortest routes out of the building; whether or not smoke blockages will occur during the evacuation; and whether full or abbreviated output will be produced.

Some of the changes made to EXIT89 were designed to fix bugs or other problems in the program and others were the addition of new features. The changes made under the grant are described in this section.

<u>Check that Routes Actually Reach Location of Safety</u>

The objective of this task was to add an input check routine to the program that would ensure that shortest paths and user-defined exit paths do in fact reach the

outside.

One subroutine was created. Called CHKRTS, this subroutine checks the connected paths stored in the array ICONN to make sure that each one leads eventually to the outside. This routine can find cases where nodes are inadvertently pointed to each other (i.e., the user has said that occupants will go from node A to node B and from node B to node A), as well as where the directed paths travel along a loop (e.g., node A to node B to node C to node A). It can also identify situations where islands exist (i.e., groups of nodes that connect with each other but not to any exit path).

For each node whose occupants will not reach an exit, a line is printed that says, "NODE xxxxx DOES NOT REACH OUTSIDE." If any such error is found, a summary line is printed that says, "SOME EXIT PATH OR PATHS LOOP. CHECK NODE DESCRIPTION SECTION OF THE INPUT."

To find the error in the input, the user must begin at the bottom of the list of nodes that cannot reach the exit. (What happens is that all nodes above the problem node(s) that connect through problem node(s) will produce an error message.) Tracing back along stairwell nodes until the lowest stairwell node on the list is reached, and then checking what nodes are directed through this node should reveal the loop.

Effect of Smoke Blockages on Deadends

Daniel Alvord at NIST identified a problem that occurred when smoke blocked a node needed by the occupants of an extended deadend. The existing check for the effect of a smoke blockage was limited to only the connected nodes. This correction checked whether the removal of a node created an island in the network. If it does, the occupants of those isolated nodes are considered trapped and all those nodes are removed from the network.

The modifications needed to correct the problem included:

- adding NTRAPT and NUMOCC to the COMMON block and changing the calls to Subroutines MOVE, RDCFST, and SETDLY so they don't use NTRAPT and NUMOCC;

- adding the running time of the model to the calls to Subroutine CHKRTS so it can distinguish between the initial call when it's just checking the input routes and later calls when it's looking for newly created and possibly occupied deadends;

- Changes to Subroutine CHKRTS to checked the one-way nodes that branch away from the blocked nodes to count any occupants and add them to the number of trapped occupants.

If in future versions of the model it is necessary to handle the exposure of trapped occupants, this modification will have to be changed. The isolated occupants can be pretty far removed from the fire and their entrapment may not mean that they cannot survive or be rescued.

Adding the presence of disabled occupants

The presence of disabled people during an evacuation is a situation that needs to be modeled by EXIT89. The strategy chosen at this time assumes, as demonstrated in work at the University of Ulster, that the presence of disabled occupants does not impede able-bodied occupants.[2]

The following modifications to the software were required to add the modeling of disabled occupants. Part of the input includes a description of each node in terms of size, number of occupants, etc. An additional variable has been added to the input lines in this section that specify how many of the occupants described are "disabled." This can mean not only how many will evacuate slower than the average occupant, but also any able-bodied people who will evacuate with someone who is disabled. People with disabilities include those whose travel speed is slowed by the use of a walker, wheelchair or age, as well as small children and those who will accompany them.

The program checks to make sure that the user does not designate more disabled occupants than there are occupants at a node. If a node has any disabled occupants, the user enters on the next line the proportion of "normal" speed that the person will move. For example, if a disabled person moves at three-quarters the speed of an able-bodied person, the user enters 0.75 as the speed factor for that person. Up to 15 entries can be made on each line. (The format is 15F5.0)

In subroutine `MOVE`, the calculations for travel times between nodes, `TIMRM(n)`, are now adjusted by the speed factor for each occupant. This array, `SFR(i)`, is initially set to 1.0 as the default for able-bodied occupants.

This method of handling disabled occupants assumes that their presence does not impede the able-bodied occupants. The densities used to calculate travel speeds for able-bodied occupants count all occupants of a node and treat them as if they were all of the same body size. This does not account for the size of wheelchairs or the space taken up by walkers and strollers, for instance. The justification for this assumption is based on the evacuations studied by the University of Ulster that showed that the presence of people in wheelchairs or with walkers did not affect the travel speed of other occupants.

In addition, with this modification, people moving at more rapid than normal speeds can be modeled by identifying them as "disabled" but setting their speed factors at some value greater than 1.0.

Specifying Delays by Location

A modification was made to the input section where nodes are described to add the amount of time (in seconds) that occupants at that node will delay before beginning to move from that location. This allows delays to be fixed by location in cases where, for example, a department would have certain tasks to perform before beginning evacuation. The location of this additional variable is described in the users manual.

Adding Random Delays

The program was further modified to add the capability of having the user set the probability of occupants delaying evacuation for some range of time (in seconds) and having the model randomly select the occupants who will delay and set their delay times. This randomly applied delay would be in addition to any location-specified delays already determined by the user.

The user can set the percentage of occupants delaying evacuation to any value from 0 and 100 percent. The user specifies a range of times (in seconds) that occupants will delay. The distribution is currently uniform, but changing the distribution would be a simple exercise.

This change was incorporated by adding a new option to the input file. This allows the user to specify whether or not s/he wants delay times assigned randomly and if so, for what percentage of the occupants and over what range of time (in seconds). A new subroutine was created. Called SETDLY, it decides for each occupant whether or not that person will delay evacuation. If the occupant will delay, a delay time is calculated using the minimum and maximum times specified by the user.

**Other EXIT89 Work**

During the period of this grant, a users manual for EXIT89 was completed. A copy is attached as Appendix A. In addition, a NISTIR, co-authored with Daniel Alvord of NIST, is in draft stage. It compares the capabilities of EXIT89 and EXITT.

In the course of writing the NISTIR, a comparison of travel speeds calculated by EXITT and EXIT89 on a small example floor plan based on the University of Ulster tests with disabled occupants with travel speeds observed in studies of people movement was also undertaken.

**Plans for EXIT89**

Daniel Alvord at NIST created a PC version of EXIT89 that includes the connection to CFAST that will allow the user to model a fire and use the smoke output as input to EXIT89. Plans are underway to have that version of EXIT89 and an updated users manual tested by a group of 4-8 people including consultants and universities in the latter part of 1995.

**World Trade Center Human Behavior Study**

Several papers have been written summarizing the analyses of data from the World Trade Center human behavior study.[3] An article on the results published in *NFPA Journal* is included in Appendix B of this report. In addition, analysis of actions by type of occupation has been attempted but is not complete.

Under this project, reports have been prepared discussing the actions undertaken by the evacuees in order to aid in the understanding of what people do in fires and why and how those actions may conform to or differ from the assumptions used in

designing and planning for life safety in such a large building.

Survey responses show that there was a significant difference in perception of severity between the two buildings since the bomb was closer to Tower 1 than Tower 2. Also, where previous human behavior studies have shown that people will move through smoke, this incident demonstrated that people will not only move through smoke, but will move through worsening conditions.

Information on pre-movement times and activities before and during evacuation were also obtained. Results to date indicate that all occupants of high-rise buildings need some level of training and that training should include enough information and/or education about basic fire physics to enable occupants to think for themselves.

## References


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2. Shields, T.J., "Fire and Disabled People in Buildings," Building Research Establishment Report BR 231, Building Research Establishment, Garston, 1993.

3. "The Study of Occupant Behavior during the World Trade Center Evacuation -- Preliminary Report of Results," presented at NFPA Fall Meeting in Toronto, Ontario by Guylène Proulx, PhD. of National Research Council of Canada and Rita F. Fahy of NFPA, November 1994.

   Proulx, G. and Fahy, R.F., "A Study of the New York World Trade Center Evacuation," Proceedings of AsiaFlam '95, Kowloon, Hong Kong, March 1995.

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# Appendix A

# User's Manual

# EXIT89
# An Evacuation Model for High-Rise Buildings

by

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## Table of Contents

## 1. Description of the Program

This model requires as input a network description of the building, geometrical data for each room and for openings between rooms and smoke data if the effect of smoke blockages is to be considered. It either calculates the shortest route from each building location to a location of safety (usually outside) or sets user-defined routes through the building. It moves people along the calculated or defined routes until a location is blocked by smoke. Affected exit routes are recalculated and people movement continues until the next blockage occurs or until everyone who can escape has reached the outside.

Evacuation can begin for all occupants at time 0 or can be delayed, with delays set for each node. Additional delays over a specified range of time can be randomly assigned to occupants. Smoke data can be used to predict when the activation of a smoke detector would occur and evacuation will begin then or after some user-defined delay beyond that time. Disabled people can be included among the occupants of the building.

The program is written in Fortran and runs on an IBM mainframe. A PC-version has been developed by Daniel Alvord at the National Institute for Standards and Technology Building and Fire Research Laboratory. The PC-version has the capability to read in CFAST-generated smoke data.

## 2. Technical Discussion

### 2.1 Characteristics and Assumptions of EXIT89

EXIT89 was developed to serve as the evacuation model in HAZARD I for high-rise applications needs. It was designed: 1) to be able to handle a large occupant population; 2) to be able to recalculate exit paths after rooms or nodes become blocked by smoke; 3) to track individuals as they move through the building by recording each occupant's location at set time intervals during the fire; and 4) to vary travel speeds as a function of the changing crowdedness of spaces during the evacuation, i.e., queueing effects.

The size of the building and its population that can be handled by EXIT89 is limited only by the storage capacity of the machine used. The dimensions of the storage arrays currently allow for up to 700 occupants in a total of 308 nodes or building spaces over 100 time intervals. These can be changed by the user to

handle larger problems. Due to the naming convention for nodes that the program relies on, each floor can have up to 89 nodes and the building can have up to 10 stairways.

The model has a local perspective rather than a global one. People will move to what looks like the closest exit, even though the total length of the path to the outside might be longer than through another exit door. For example, an occupant of a hotel stepping out of his room will head to the closest stairwell even though it may be five flights down to grade level while another stairwell a slightly greater distance from his room might be only three flights from grade level. A model with a global perspective would move him along the truly shortest path, but that route would not be realistic for a hotel guest who would be unfamiliar with the layout of the building.

Another assumption is that once people enter a stairwell, they will follow it all the way down to the outside unless it becomes blocked by the fire's progress, in which case they will move out of the stairs and onto the nearest floor. In real situations people may head for the roof or leave the stairs to go onto lower floors for no apparent reason.

EXIT89 does not explicitly include the behavioral considerations that are included in some other evacuation models. These behaviors include investigation of the fire, rescue of small children, alerting or waking other capable adults and assisting other occupants that may require help. The population of high-rise buildings is too large to handle so much detail for each individual, and behaviors such as investigation or rescue of other occupants are not as relevant in larger, more impersonal, buildings.

Walking speed in the model is calculated as a function of density. How this is handled is discussed in Section 2.4. Disabled occupants are modelled by setting their walking speed as a user-specified fraction of the calculated "normal" walking speed.

The input to the model includes a network description of the building. Nodes can be rooms or sections of rooms or corridors, whichever will result in the most realistic travel paths. The nodes defined, though, should correspond to the rooms or a subset of the rooms described in CFAST, if CFAST output will be used as the smoke data input for EXIT89.

The definition of each node includes its useable floor area, the height of the ceiling, the capacity of the node, its initial occupant load, the number of disabled occupants at that node, the number of seconds occupants of that room will delay

before beginning evacuation, and the node occupants will move to if the user chooses the option of having occupants move along defined routes. The definition of each arc includes the distance between nodes and the width of the opening between the nodes. Arcs are bidirectional so a connection between two nodes only has to be described once. Escape via windows is allowed by assigning a very large value as the distance along the arc so that that route will only be used as a last resort.

EXIT89 can be used in two different ways. The user can input the names of nodes that become blocked by smoke and the time those blockages occur. Or, the user can take the smoke data output from CFAST as input to the model. CFAST will calculate and write to a disk file the optical density of the hot upper layer at each node at each time interval and the height from the floor of the cooler lower layer. In the first version, evacuation begins simultaneously throughout the building at time 0, plus any delay time specified at nodes by the user or randomly assigned by the model. In the second version, evacuation begins throughout the building when the smoke level reaches that defined for smoke detector activation, plus any delay time specified at nodes by the user or randomly assigned by the model. By using the first version and not specifying any blockages, the user can model emergency evacuation of a building with no fire occurring.

The program will print out the movement of each occupant from node to node. It also records the location of each occupant at each time interval so that the output can be used as input to TENAB. TENAB will calculate the hazards to which each occupant was exposed using CFAST output for combustion products and will determine when incapacitation or death occurs. The user can suppress this output and have the model only print out a summary showing floor clearing times, stairway clearing times and last time each exit was used and how many people used each exit.

### 2.2 Shortest Route Calculations

The user has the option of specifying the routes occupants will take or using shortest routes calculated by the model. Shortest routes are calculated for each floor, from each node to the stairways or to the outside. The shortest route algorithm used is that described by Hillier and Lieberman as the shortest and simplest of those they reviewed.[1] The algorithm begins by identifying the origin of

a network and then fans out from the origin, identifying the shortest routes to all the other nodes until the destination is reached.

The adapted version of the algorithm used in the model is described below. The model calculates the shortest routes on each floor to the stairways or the outside or other locations of safety. Locations of safety can include horizontal exits or areas on the other side of fire doors. In order for the model to recognize these locations of safety, the user identifies them as part of the building description input data. These nodes are referred to as intermediate exits (IE) in the following discussion. An array is created that consists of the connected node that occupants at a given node will move to in evacuating the building. For example, if the path from node 102 to the outside goes through nodes 104 and 107, then the connected node for 102 is 104, the connected node for 104 is 107 and the connected node for 107 is the outside. The route down each stairway is then established by defining the connected node for each stairway node as the one below it.

The shortest route subroutine begins by identifying all the IE's on a floor of the building. These nodes are placed on the list of *solved nodes*.

Step 1 Identify all unsolved nodes connected to the solved nodes.

Step 2 Add the distance between the solved and unsolved nodes to the distance from the solved node to its closest IE.

Step 3 The unsolved node with the shortest distance to the IE is added to the list of solved nodes, its connected node is that solved node and its distance to the IE is stored.

Return to Step 1 until all nodes are solved.

This is repeated for each floor.

One advantage of the approach used in EXIT89 is that the blocking of a node by smoke will only require the recalculation of the routes on that floor, rather than all routes throughout the building. If a stairway node is blocked by fire, the routes on that floor and the floor above will be recalculated. This will cause occupants in the stairway on higher floors to move out of the stairway when they reach the node above the smoke-blocked node.

Another advantage of this approach is that it more closely approximates the local perspective of an occupant in the building. Other shortest route routines "see" all possible routes to the outside and so they make decisions based on information not available to a real person.

The user also has the option of naming the node occupants will move to from each node in the network. It is often observed in actual evacuations that people follow the route they are most familiar with and this option allows the user to model that behavior. It also allows the user to model travel observed in an evacuation. If that option is used and a node becomes blocked by smoke, the routes on the affected floor(s) will be recalculated using the shortest route subroutine.

### 2.3 Calculation of Walking Speeds

The method chose for EXIT89 uses walking speeds calculated as a function of density based on formulas from Predtechenskii and Milinskii.[2] Body size is included in their density calculations. Using dimensions of people (adults, youths, and children) in various types of dress, both empty-handed or encumbered with packages, knapsacks, baggage or babies, they calculated the area of horizontal projection of a person. This measure is the area of an ellipse whose axes correspond to the width of a person at shoulder level and breadth at chest level. Tables of mean values for different age groups and types of dress are given in the text. Their formula for density of a stream of people, D, is:

$$D = Nf/wL \quad (m^2/m^2)$$

where

- N = number of people in the stream
- f = the area of horizontal projection of a person
- w = width of the stream
- L = length of the stream

Their model established an optimal density of 0.92. Although a higher density can be observed in real situations, 0.92 is the maximum they used in empirical expressions for walking speeds. Based on their observations recorded in thousands of situations, they developed the following equations for normal circumstances. For the mean values of velocity as a function of density for horizontal paths:

$$V = 112D^4 - 380D^3 + 434D^2 - 217D + 57 \quad (m/min)$$

for $0 < D \leq 0.92$

For movement through doors

$$V_o = Vm_o \quad \text{(m/min)}$$
where $m_o = 1.17 + 0.13 \sin(6.03D_o - 0.12)$

For movement down stairs

$$V_{\downarrow} = Vm_{\downarrow} \quad \text{(m/min)}$$
where $m_{\downarrow} = 0.775 + 0.44e^{-0.39D_{\downarrow}} \bullet \sin(5.61D_{\downarrow} - 0.224)$

Since the model does not move people up stairs, the values for travel up stairs is not shown.

In emergencies, such as earthquakes or fire, the fear that makes people try to flee danger raises the speed of movement at the same densities. Predtechenskii and Milinskii found the following relationship between the two velocities:

$$V_e = \mu_e \bullet v$$
where $\mu_e = 1.49 - 0.36D$ for horizontal paths and through openings

$\mu_e = 1.21$ for descending stairs

Repeatedly calculating velocities using these equations for every occupant throughout a fire simulation would be extremely time consuming. Fortunately, tables of velocities by density were given for normal, emergency and comfortable movement along horizontal paths, through openings and on stairs. EXIT89 allows the user to select between normal and emergency velocities.

The area of horizontal projection of a person estimated from Russian data is 1.2173 $ft^2$ (0.113 $m^2$) -- the mean dimensions of an adult in mid-season street dress. The user can select other values from measurements of Austrian and American subjects. Velocities are calculated for both segments of the arc between two nodes, based on the different densities and floor areas for the two nodes. If a value for D greater that 0.92 is calculated, D is set equal to 0.92. The value calculated for D is used to look up the velocity from the tables. The table holds velocities along horizontal paths and down stairs.

Initially, the program was coded the way the formulas were given; that is, the density was based on the area of the stream -- the width of the doorway by the length of the stream of people. This resulted in reduced velocities even when only two people were in a room, and could noticeably decrease walking speed when, say, six people were in even a fair-size room. People don't necessarily line themselves up so closely when evacuating through rooms. They can spread out and so maintain a more rapid, free-flowing walking speed. The formulas used in the model now calculate densities based on the floor area of the nodes. For travel along corridors, the useable floor area and the area of the stream as calculated by Predtechenskii and Milinskii will be very close, if not identical.

EXITT reduces the travel speed of occupants who are crawling in smoke. This model does not do that yet. First, a mechanism must be inserted in the code to detect conditions at a node where crawling would be necessary. The routes on that floor should be recalculated to move people away from that node. Then if moving through a smoky node is the only way out of the building, the velocity would be adjusted.

### 2.4 Body Size Data

Predtechenskii and Milinskii's work used body sizes calculated from the measurements of Soviet subjects. Subsequent work by Ezel Kendik using Austrian subjects found significant differences in the results.[7] The value of 0.113 $m^2$ described above compares to the Austrian result for subjects between the ages of 10 and 15 years without coats. The value for Austrian subjects between ages 15 and 30 wearing coats was 0.1862 $m^2$ and without coats was 0.1458 $m^2$. The value for adults over age 30 without coats was 0.1740 $m^2$.

A table of mean body dimensions representative of U.S. male and female workers between 18 and 45 years of age was obtained from *Occupational Safety and Health in Business and Industry*. From this table, mean values for shoulder breadth (.455 m for men, .417 m for women) and chest depth (.231 for men, .234 for women) were obtained. In order to add the additional bulk of clothing, the table of Russian data were checked. That table included values for summer dress, mid-season street dress and winter street dress. The values increased by 0.02 meters between each category of clothing. Based on this, then, the American values for shoulder breadth and chest depth were increased by 0.02 meters. To obtain one "American" value for horizontal projection of a person, the mean values for men

and women were averaged. The resulting value was 0.0906 $m^2$, far smaller than that calculated for Soviet or Austrian subjects. The choice between the three sets of data is an input option set by the user.

### 2.5 Smoke Levels

As mentioned above, there are two ways to handle smoke. In the first, the user determines at what node and when blockages due to smoke will occur. In the second version, smoke densities and depths of smoke layers are read in from a file created by CFAST. Using the same method as EXITT of calculating the psychological impact of smoke, S, the following equation is used:

$$S = 2 * OD * D/H$$

where OD is the optical density of the smoke in the upper layer,
D is the depth of the upper layer, and
H is the height of the ceiling.

EXITT uses $S > 0.5$ to stop an occupant and $S > 0.4$ as a threshold to prevent entering a room, in both cases unless there is enough clear air in the lower layer to crawl. Since this model does not yet handle crawling, a value of $S > 0.5$ is used to block a node which traps everyone currently at that node.

Smoke detectors operate when $S \geq 0.015$ and the depth of the upper layer is greater than 0.5 feet (0.15 meters). The model currently assumes that notification of all occupants occurs when levels needed for smoke detector activation are reached at any node, and evacuation will begin after any user-specified delays. Refinements of the program to define the range of a smoke detector and to otherwise modify the rules determining the notification of occupants have not yet been done.

### 2.6 Moving the Occupants

When the user chooses the shortest route option, the initial shortest routes throughout the building are calculated before any smoke data is read in. Where the user enters the location and time of smoke blockages, notification to begin evacuation occurs at time 0. If the user uses CFAST data, the model reads in the

smoke data and determines where and when blockages would occur and when smoke detector activation would occur and evacuation would begin.

The model begins by calculating, based on the initial distribution of occupants, how long it would take to travel from each occupied node to its connected node. Then, for each occupant, it looks at how long that occupant has been at that node and how long it takes to traverse the arc. If the occupant has been waiting long enough to traverse the arc, the occupant is moved to the next node, and the waiting time at that node is set to 0. Waiting times are actually portions of the arc traversal times. If there are still occupants in the building, the model recalculates time to traverse arcs based on the updated densities at nodes.

The sequence is repeated until the time is reached when a node is blocked by smoke. At that point, the affected node is removed from the network, any occupants at that node are counted as trapped and shortest routes are recalculated for the affected floor (or floors if the node is in a stairway). People movement is then resumed until the next blockage or until everyone is either out or trapped.

Queueing is handled by the decreased walking speeds that result from increased densities as more occupants move into a room or stairway. The program does not currently allow occupants to select less crowded routes. They simply join the queue at nodes along the shortest route.

## 3. Developing the Input

The process of converting information about the building and its occupants into an input file the program can read is described in this section. The smoke output from CFAST, if used, is written to a file that is read in by EXIT89.

The input file format is described in Attachment A. The list of program variables can be found in Attachment B.

The first line in the input file is a 72-character title line that the user can use to describe the model that is being run. The next several lines allow the user to select among several options. First the user indicates whether the measurements in the input are metric or standard. Next, the user picks the body size measurement to be used in the density calculations. The next option allows the user to specify whether occupants will be traveling at emergency or normal (slower) velocities. Next, the user indicates whether the program should calculate the shortest paths between nodes or whether the user will be specifying

the node to which occupants will move from each node. Next, the user indicates whether there will be data from CFAST (option 1) or whether there will be user-defined blockages or no blockages at all (option 2). Next, the user selects full output, which prints out every time someone moves from one space to another, or summary output. And finally, for that section, the user enters the number stairways there are on the floorplan.

On the next two lines, the user indicates whether or not additional delay times should be randomly distributed among the occupants. If yes, the user then specifies for what percentage of the occupants there will be additional delays and over what range of time (in seconds) those delays should be chosen. (Right now, the times are selected from a uniform distribution, although data indicates that the observed distribution is not uniform. This is a simple modification.)

### 3.1 Building Network

The next section of the input stream holds the network description of the building layout. Constructing the building network is the most complicated and time consuming part of setting up the data stream. A network is a collection of nodes connected by links or arcs. The nodes represent locations in the building and the links represent the travel paths along the network. A floorplan of the building is required in constructing the network.

The first step is to decide where the nodes should be placed. Not all spaces in the building need to be included, but areas not included are not considered in the evacuation. Unoccupied areas such as storage rooms, or spaces through which evacuees do not need to pass, do not need to be described.

Nodes are placed in the center of the location they describe, and usually each compartment is represented by a node. Large spaces are often represented by more than one node when doing so allows a more realistic representation of travel paths without excessively increasing the size of the network. For example, in a hotel, a long corridor with several rooms opening onto it would have more than one node describing sections of the corridor. Common sense is an important criterion in determining node placement, but it is also possible to test the appropriateness of the placement by using data from fire drills. Too many nodes unnecessarily clutter the network and increase the program's execution time. Too few nodes may result in unrealistic travel paths and a loss of detail in the output.

For stairways, the center of the node is taken as the stairway landing at floor level. The boundaries of a stairway node are the landings halfway up to the floor above and halfway down to the floor below.

Once the nodes have been positioned at the center of the spaces they describe, the network input section can be developed.

The node names are three or four digit integers where the first one or two digits are the floor number and the last two digits uniquely number the spaces on that floor. Numbers 90 to 99 are reserved for stairways. There can be up to 89 occupant spaces on each floor. Locations of safety, including outside the building, are named "000."

Each arc on the network is described by the two connected nodes, the distance from the first node to the opening between the two locations (called `XLNGS1`), the width of the opening (called `RESWTH`), and the distance from the opening to the second node (called `XLNGS2`).

The procedure for computing these distances is as follows:

1. The nodes are placed at the center of the spaces they represent.
2. The opening is the dividing line between two connecting spaces. Between two compartments, the opening width would be the width of the doorway. For two nodes along the corridor, the opening width would be the width of the corridor. If a large room is divided into two or more spaces, the opening width is the width of the room along the invisible line dividing these spaces.
3. For horizontal paths, the lengths of the two segments of the arcs are measured in straight lines from the node to the center of the opening.

The following method from Predtechenskii and Milinskii should be used to calculate paths on stairways.

For calculating the length of the inclined path, L,

$$L = L'/\cos\alpha$$

where

$L'$ = horizontal projection of the length of the inclined path, and

$\alpha$ = angle of inclination to the horizontal.

Since most slopes are between 1:1.75 and 1:2, with an angle between 30° and 32°, the value of $\cos\alpha$ is approximately 0.85.

For two-flight stairs

$$L = 2L'/\cos\alpha + 4b$$

where

$b$ = length of the landing (width of path).

For three-flight stairs

$$L = L'(3/\cos\alpha + 1) + 4b$$

If the slope is less than 1:8, it can be considered horizontal.

In constructing the network, a decision has to be made as to whether the situation to be modeled will use only legal or allowed means of egress, or if any means used or likely to be used is included. If the user wants to include a window as an escape route, the distance along the second segment of the arc should be a very large number so that it will only be considered as an escape path as a last resort.

The description of the links can now be added to the input section. The links can be entered in any order. Whether travel along a path would be bidirectional or one-way, each link should only be entered once.

The link description is entered in this way:

`INODE` is the from-node.

`XLNGS1` is the distance from the first node to the center of the opening.

`RESWTH` is the width of the opening.

`XLNGS2` is the distance from the center of the opening to the second node.

`JNODE` is the to-node.

The end of this segment of the input file is indicated by a record showing a from node called 9999 with all associated entries coded as zeroes.

### 3.2 Node Descriptions

The second part of the network input consists of the node descriptions. Each description includes the node name, its useable floor area, the height of the room, the number of people that space can hold (not used yet so any value can be entered), the number of people at that node when the fire begins, the number of

people at that node who are disabled, a flag that indicates whether or not the node is an IE, the amount of time occupants at that node will delay evacuation (in seconds) and the node occupants of that room will travel to if directed routes are used instead of calculated shortest routes. For any node above the first floor that is part of the stairway and first-floor nodes that connect to the outside are indicated by setting the IE flag equal to one. Otherwise the flag should be zero.

When the user indicates that one or more of the occupants at a node are disabled, a value is entered that indicates at what percentage of the calculated speed for an able-bodied person a disabled occupant will travel. A different percentage can be entered for each person.

The node descriptions must be entered in ascending order in this way:

`N` is the node being described.
`NAREA` is the useable floor area at that node.
`H` is the height of the ceiling at that node.
`NCAP` is the capacity of the node.
`NOCC` is the number of people there initially.
`ND` is the number of disabled people.
`IE` is the flag.
`EVACTM` is the time that occupants of that node will delay before beginning evacuation.
`ITO` is the node along a directed path that occupants will move to (optional).

There has to be one record for each node mentioned in the list of network links.

If any occupants of a node are described as disabled, an input line must follow the node description giving the percentage of "able-bodied" speed that each disabled occupant will travel. Up to 15 disabled occupants can be described on one line.

### 3.3 Entering Blockages by User

If a smoke spread file from CFAST is not available, the user can enter smoke blockages. In that case, at the end of the input data, the user enters the name of the blocked node and the time from the start of evacuation that the blockage occurred (in seconds). More than one node can be blocked at a time. To

indicate the end of this section of the input, the user should enter a final record with 9999 for each entry.

To model the evacuation with no fire, the user just enters that last record.

### 3.4 Using Smoke Data from CFAST

The mainframe version of EXIT89 documented in this users manual does not handle CFAST input. That capability has been added to the PC version of the model and is documented in the draft NISTIR.

## 4. Logic Flow of the Model

This section describes briefly the logic of the model. The program begins by printing some identifying information, displaying the options selected by the user and the probability data, if any, to used to calculate random delay times for occupants.

The list of network links is read in next. After each link is read into the array where they are stored, the reverse direction along the link is stored in the array. Only links to the outside are not reversed. These arrays are then sorted in order by from-nodes.

The node descriptions are then read in. An array of occupant locations by time interval is created using the number of occupants at each node. The array of times to delay evacuation is also created at this time. If the user specified that some occupants at a node are disabled, the program then reads in the percentage of "able-bodied" speed at which each such occupant travels. These percentages are storied in an array called `SFR`. The value stored for able-bodied occupants is initialized at 1.0. The program prints out the identity and initial location of each disabled occupant and that person's `SFR` value.

If the user selected the option of randomly assigning additional delays to a percentage of the occupants, that is done in the next section. The program then prints out the total delay time for each occupant.

If the user selected the option of having the model calculate shortest routes, the program then calculates the shortest paths on each floor to stairways or to the outside, based on the network description that was read in. Paths down stairways are then set. Since all nodes in a stairway end with the same two digits, this

subroutine simply links, for example, node 398 to node 298 and node 298 to node 198 to move occupants down stairs.

The two versions diverge at this point. If the user is entering the location and time of blockages, this data is read in and an array that stores the conditions at each node over time is updated to record the blockage. If the data is read in from CFAST, the psychological impact of the smoke is calculated to determine if blockage has occurred. When it does, the array of conditions at each node is updated. The time that smoke detector activation would occur is also stored in that array. If the user entered a delay in evacuation for occupants of that node, that delay will be updated to be beyond the time until smoke detector activation. From that point on, both versions of the program work the same way.

The final part of the input section of the mode is a subroutine that checks the travel paths for both user-defined egress and shortest paths to make sure that all node each the outside. This routine identifies nodes that have may include loops that would prevent occupants from ever reaching the outside.

The evacuation then begins. The program checks the array of hazard levels throughout the building until it finds a location where the smoke levels block a node. The program then moves the occupants as described in Section 2.6 along the defined or calculated shortest paths until the time when a node is blocked. The program then removes from the network all nodes blocked at that time and recalculates the shortest routes on the affected floors. The program then checks for the next time interval when a node is blocked, repeating the cycle until all occupants have escaped or are trapped.

# Attachment A

## Input File Format

This appendix describes the format of the input data stream, in summary form. It contains the FORTRAN formats for the input used in the mainframe version, and information concerning the order in which the input must be entered. The process of building the input file is covered in more depth in the body of this report.

The variables themselves are described in Attachment B.

## Description of Input

Title of Run - Card 1 `(18A4)`

| Field | Variable | Description |
|---|---|---|
| 1 - 18 | TITLE | Title of run can appear anywhere within these 72 characters |

User Options - Cards 2 through 8 `(6(29X,I1,/),29X,I2)`

| Field | Variable | Description |
|---|---|---|
| 1 | IUNITS | Choice of measurement units to be used<br>1 - metric<br>2 - standard |
| 2 | ISIZE | Choice of body size data<br>1 - Austrian (0.1458 $m^2$)<br>2 - Soviet (0.1130 $m^2$)<br>3 - American (0.0906 $m^2$) |
| 3 | ISPEED | Choice of velocity<br>1 - emergency<br>2 - normal |
| 4 | IOPT | Exit routing option<br>1 - calculated shortest routes<br>2 - directed paths entered by user |
| 5 | ISMK | Source of smoke data<br>1 - CFAST output<br>2 - User-defined blockages or no smoke |
| 6 | IFULL | Output option<br>1 - full output showing each move<br>2 - summary output |
| 7 | NSTR | Number of stairways in floorplan |

Optional Random Delay - Cards 9 and 10 (24X,I1,8X,I3,/,20X,F4.0,18X,F4.0)

| Field | Variable | Description |
|---|---|---|
| 1 | IDLY | Random delay option<br>1 - yes, assign additional delays randomly<br>2 - no random delays |
| 2 | IPROB | Probability of delaying (i.e., the percentage of occupants who will be assigned additional delay times |
| 3 | XMIN | Minimum value for uniform distribution from which delays will be selected (seconds) |
| 4 | XMAX | Maximum value for uniform distribution from which delays will be selected (seconds) |

Network Link Descriptions - one card for each arc (I5,3F6.1,I5)

| Field | Variable | Description |
|---|---|---|
| 1 | INODE | From-node (use 9999 to indicate end of list) |
| 2 | XLNGS1 | Distance from the center of the first node to the center of the restriction or opening between nodes |
| 3 | RESWTH | Width of restriction or opening between nodes |
| 4 | XLNGS2 | Distance from center of the restriction or opening between nodes to the center of the second node |
| 5 | JNODE | To-node |

Node Descriptions - one card for each node (I5,F5.0,F6.1,4I5,F6.1,I5)

| Field | Variable | Description |
|---|---|---|
| 1 | N | Node being described |
| 2 | AREA | Floor area of node |
| 3 | H | Height of ceiling at node |
| 4 | NCAP | Capacity of node (not used yet, enter anything) |

| | | |
|---|---|---|
| 5 | NOCC | Number of occupants at that node |
| 6 | ND | Number of occupants at that node who are disabled |
| 7 | IE | Indicates if a node is an intermediate exit (i.e., a location such as a stairwell or the node before an exit that people will head to in leaving the building)<br>1 - is an IE<br>0 - is not an IE |
| 8 | EVACTM | The length of time people at this node will wait after notification before they begin evacuation |
| 9 | ITO | Node to which occupants will move if directed route option was selected |

Description of Disabled Occupants - immediately follows any node description where ND $\neq$ 0 (15F5.2)

| Field | Variable | Description |
|---|---|---|
| 1 - ND | FACTR | Percentage of "able-bodied" speed at which each disabled occupant will travel |

Smoke blockages - if ISMK = 2 - one card for each blockage (I5,F5.0)

| Field | Variable | Description |
|---|---|---|
| 1 | N | Node at which blockage occurs (enter 9999 to indicate end of this input section) |
| 2 | TIME | Time at which blockage occurs |

# Attachment B

## Description of Program Variables

The variables for this program are described in this Attachment.

| Variable | Description |
|---|---|
| AREA (NBL) | Input variable. The floor area of the node being described. |
| DENSTY | The body size used in the density calculations for travel speed. |
| ENDDAT | Logical variable indicating that the end of the data file has been reached. |
| ETIME (NUMOCC) | 1. In the input section, this array holds the time that each occupant will delay evacuation after receiving notification of a fire.<br>2. During the people movement phase of the program, this array holds the length of time that each occupant has been moving along the path from one node to the next. |
| EVACTM | Input variable. The time the occupants of a node will delay before beginning evacuation. |
| FACTOR (15) | Input variable. When the user has indicated that some occupants of a node are disabled, this array holds the percentages of "able-bodied" speed at which each disabled occupant will travel. Up to 15 people can be described on each line. This data is stored in the array called `SFR()`. |
| FULL | Logical variable indicating that the user has selected full printed output. |
| H (NBL) | Input variable. Height of the ceiling at each node. |
| ICONN (NBL) | For each node, the node connected to it along the exit route. Either calculated by shortest route routine or input by the user. |
| IDIR (NBL+1) | Directory for the nodes in the network link list, `JNODE()`. |
| IDLY | Input variable. Indicates whether or not additional delays will be randomly assigned to occupants. |
| IE (NBL) | Input variable. For each node, this is a flag that indicates whether or not that node is a destination for occupants on that floor. Its value is 1 if it is; otherwise, it is set equal to zero. |

| | |
|---|---|
| IEND | Subscript for the last node on the floor (used in shortest route subroutine). |
| IFDIR (NFLR+1) | Directory for the location of nodes for each floor within the array INODE(). |
| IFLAG (NFLR) | This array indicates whether or not a floor is empty (1 - empty; 0 - occupied). |
| IFLR | Floor being considered by the shortest route subroutine. |
| IFLSTR (NSTR) | This array indicates whether or not a stairway is empty (1 - empty; 0 - occupied). |
| IFULL | Input variable. Indicates whether user wants full output (1) or summary output (2). |
| INC | Holder for the increment at which an event occurred. |
| IND (NBL) | This array indicates whether or not a node is blocked.<br>1 - blocked<br>0 - open |
| INEXT | For the calculation of shortest routes, this variable indicates which node is the first node on the next floor. |
| INODE (NLINK) | 1. In input section, the from-nodes in the network.<br>2. After the input section, the first NBL elements are the node names. |
| IOPT | Input variable. Indicates whether the user wants the program to calculate shortest paths (1) or will input the nodes to which occupants will travel (2). |
| IPROB | Input variable. Indicates the percentage of occupants for whom random delays will be assigned. |
| ISIZE | Input variable. Indicates which source of body size data the user wants to use (1 - Austrian, 2 - Soviet, 3 - American). |
| ISMK | Input variable. Indicates either that smoke data will be provided by a CFAST output file (1) or that the user will input smoke blockages or there will be no smoke (2). |
| ISPEED | Input variable. Indicates whether travel velocities should be emergency (1) or normal (2). |

| | |
|---|---|
| ISTRT | Subscript for the first node on the floor (used in shortest route subroutine). |
| ITEMP | Dummy variable used to read through input section when too many network links are entered. |
| IUNITS | Input variable. Indicates whether measurements are metric scale (1) or not (2). |
| J (NBL) | Used in the shortest route subroutine to indicate whether or not a node is "solved." |
| JNODE (NLINK) | 1. In input section, the to-nodes in the network.<br>2. After input section, it holds the link list indexed by IDIR. |
| LENGTH (NBL) | Used in the shortest route subroutine to hold the length of the path from each solved node to the nearest IE. |
| LEVHAZ (NBL, NINC) | This array holds the hazard level at each node at each time interval. It serves as a holder for the times when smoke conditions reach the level that will block access to the room (LEVHAZ = 4), or when smoke conditions reach the level that will activate a smoke detector (LEVHAZ = 1). |
| MAXLNK | The maximum number of links on the network given the dimensions of the arrays. Set at beginning of the program. |
| MAXNBL | The maximum number of nodes allowed given the dimensions of the arrays. Set at the beginning of the program. |
| MAXOCC | The maximum number of occupants given the dimensions of the arrays. Set at the beginning of the program. |
| METRIC | Logical variable used to indicate whether or not metric measurements were used in the input. |
| N | Counter used as subscript when reading in list of links. |
| NAREA (NBL) | Input variable. The usable floor area of a node. |
| NBL | The number of nodes or building locations in the network. Calculated by program based on input. |
| NBL1 | NBL + 1 |
| NCAP (NBL) | Input variable. The capacity of a node. (Not used yet.) |

| | |
|---|---|
| `NDISAB` | Total number of disabled occupants. Calculated during input section. |
| `NFLR` | Number of floors in building. Calculated when directory of floor nodes, `IFDIR()`, is being built. |
| `NINC` | Number of time increments over which the simulation will be run. Set at the beginning of the program. |
| `NLINK` | The number of links in the network. (This will be less than or equal to twice the number of arcs described in the input section and will be calculated by the program.) |
| `NOCC (NBL)` | The number of occupants at a node. |
| `NSTR` | Input variable. Number of stairways. |
| `NTRAPT` | Number of people trapped in the building by smoke. |
| `NUMOCC` | The total number of occupants in the building. Calculated by the program based on input. |
| `OCCLOC(NUMOCC,NINC)` | The location of each occupant at each time interval. |
| `RESWTH (NLINK)` | Input variable. The width of the opening between nodes. |
| `SFR (NUMOCC)` | This array holds the "speed factor" for each occupant. The value for each able-bodied occupant is initialized at 1.0. The value for disabled occupants is an input variable. |
| `TABLE (92,2,2)` | Table of velocities calculated by Predtechenskii and Milinskii's method. The first subscript is calculated density (1 to 92), the second indicates the level of the travel path (1 - horizontal; 2 - down stairs) and the third indicates user-specified travel speed (1 - emergency; 2 - normal). |
| `TEXIT (2,NBL)` | This array stores in the first column the number of people who used each exit in the first and in the second column the time at which the last person passed through that exit. (Entries are only recorded in the array for the nodes that access locations of safety.) |
| `TFLR (NFLR)` | The time at which each floor was cleared. |
| `TIME` | In input section, the time at which the associated node will be blocked by smoke. This input section is used |

| | |
|---|---|
| | when the user is specifying blockages, rather than reading them in from a CFAST file. |
| `TIMINT` | The time increments at which progress of the fire and/or evacuation are recorded. Set at beginning of program. |
| `TIMRM (NBL)` | This array holds, for each node, the time it will take the occupants of that node to travel to the connected node, given the current densities of the two nodes. |
| `TITLE (18)` | Input variable. The title of the run. |
| `TRUN` | The running time of the building evacuation. |
| `TSTR (10)` | The time at which each stairway was cleared. |
| `XLNGS1 (NLINK)` | Input variable. Distance from the center of the first node on an arc to the center of the opening between nodes. |
| `XLNGS2 (NLINK)` | Input variable. Distance from the opening between two nodes on an arc to the center of the second node. |
| `XMAX` | Maximum value (in seconds) for uniform distribution from which random delay times for occupants will be selected. |
| `XMIN` | Minimum value (in seconds) for uniform distribution from which random delay times for occupants will be selected. |

## References

1. F.S. Hillier and G.J. Lieberman, *Introduction to Operations Research*, 3rd edition, Holden-Day, Inc., Oakland, California, 1980.

2. V.M. Predtechenskii and A.I. Milinskii, *Planning for Foot Traffic Flow in Buildings*, Amerind Publishing Company, Inc., New Delhi, 1978.

Appendix B

"Collective Common Sense: A Study of Human Behavior During the World Trade Center Evacuation"

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# Collective Common Sense:

# A Study of Human Behavior During the World Trade Center Evacuation

***Results from this study will help us document engineering details that affected behavior during this incident, improve fire safety in similar occupancies, and develop more effective emergency evacuation models.***

Shortly after noon on February 26, 1993, more than 100,000 people were evacuated from the World Trade Center plaza in New York City after a bomb exploded in a subterranean garage. Six employees died in the explosion, and more than 1,000 people were treated for injuries they suffered during the explosion and the evacuation. In addition, the explosion and subsequent fire caused extensive structural damage to several basement levels.

The fire itself was confined to the garage and involved 25 to 30 vehicles parked near

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the explosion site. However, smoke from the fire and the bomb, as well as structural dust, spread up the elevator shafts and migrated to upper floors. Few in the twin towers heard any alarms, and without cues from the disabled emergency system, many had to decide for themselves how to escape from the smoky buildings.

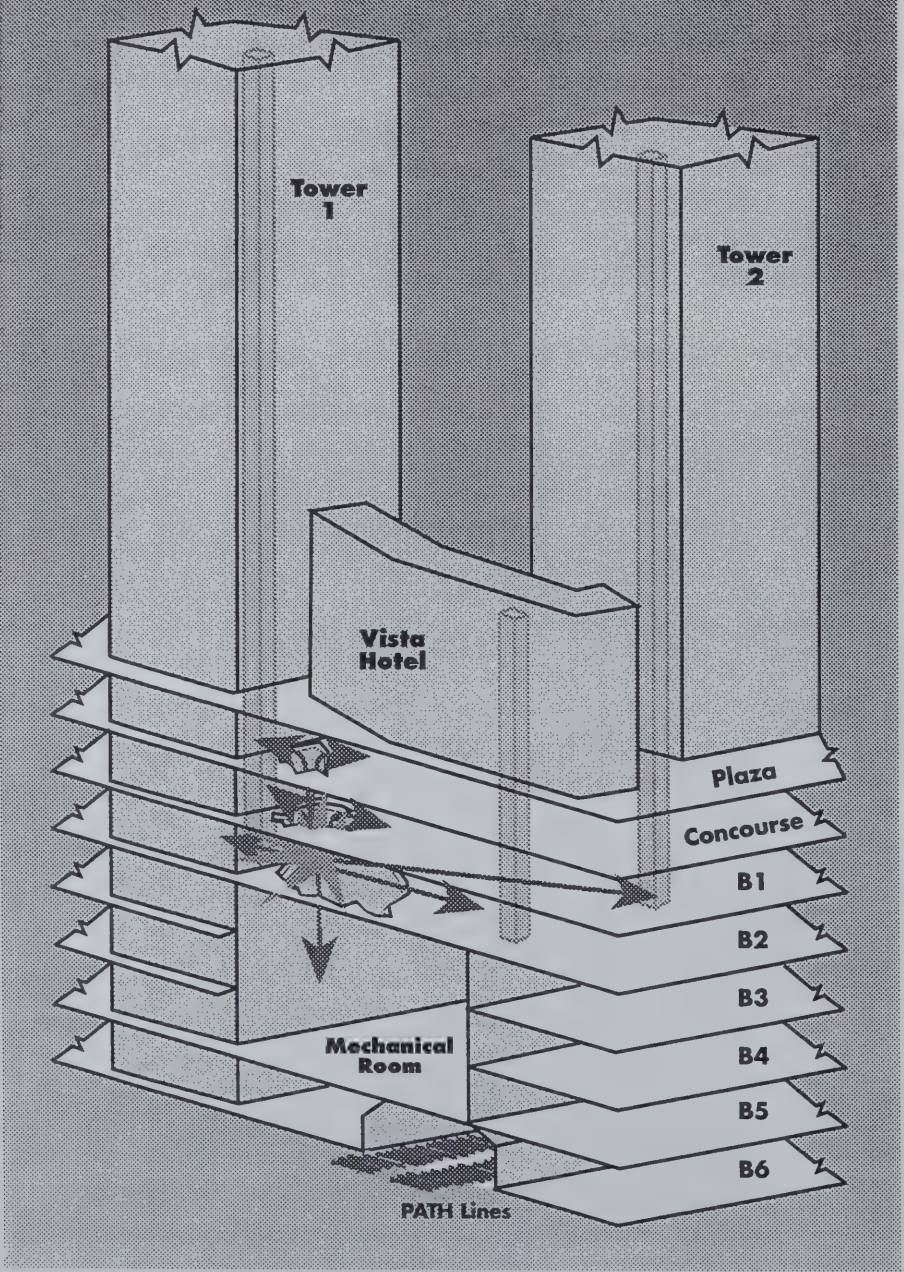
The World Trade Center is a complex of seven buildings, six of them situated on the plaza. Twin 110-story office towers are joined at sidewalk level by a 22-story hotel. The other three buildings on the plaza are 6 and 8 stories tall.

Approximately 40,000 people work in each tower, and an estimated 50,000 visit the two towers during the course of a normal business day. Both towers, as well as the other buildings on the plaza, were evacuated on the day of the explosion. The seventh building, located across the street, was not affected by the explosion or the smoke spread.

Preliminary results from this study, funded by the National Institute of Standards and Technology, the General Services Administration, the NFPA, and the National Research Council of Canada, concern only the people who were evacuated from the two towers, from floors 11 and above. Analyses of other occupants' behavior will be conducted later.

FIGURE 1

Location of the World Trade Center Explosion




Human behavior data gathered from this project will help us generalize from individual experiences in order to better understand what people do in fires and how their actions conform to the assumptions used in planning for life safety in large buildings. This study is designed to document, to the extent possible, engineering details that affected behavior, such as building design, fire safety features, and smoke spread. The results will help us work toward improving fire safety in similar occupancies and develop more effective emergency evacuation models. The information elicited will also complement the technical investigation conducted by the NFPA and will contribute to the body of knowledge used for modeling evacuations of high-rise buildings worldwide.[1]

### Study design

The Port Authority of New York and New Jersey, which owns and operates the World Trade Center complex, implements a fire safety training program that requires every tenant to appoint a fire warden trained in building evacuation. Each tenant is supposed to conduct at least two fire drills a year. Any tenant holding space on more than one floor must appoint a fire warden for each floor. Twenty-five fire safety directors coordinate the fire wardens' activities, and these directors are, in turn, supervised by two Port Authority employees.

We surveyed only the fire wardens of the 1,200 tenants in the complex for a sample that covered every occupied floor and was a manageable size—a total of 1,598 people. Although the fire wardens represented less than 1 person in 50 of those in the building, we felt that their special training gave them a context for describing what happened, giving us a comprehensive and valid basis for analysis. Since it would have been prohibitively expensive, both in terms of time and staff, to survey the tens of thousands of people who evacuated the complex that day, we contacted only this subset of the population. Special characteristics of the buildings' population make this decision technically appropriate, as well as financially feasible.

This study was based on a design originally developed by Dr. John Bryan of the University of Maryland. His model was first used for Project People in the 1970s. The NFPA has enhanced Bryan's design and applied it to studies of several fires over the years, including investigations of the fires at the Beverly Hills Supper Club, the MGM Grand Hotel, and the Westchase Hilton Hotel. NFPA used this method most recently to study the

Westin Hotel fire in Boston on January 2, 1984.

For the World Trade Center study, we designed a structured questionnaire and mailed it to the 1,598 fire wardens, assistant fire wardens, and designated searchers and rescuers identified by the Port Authority of New York and New Jersey. To encourage cooperation, we promised strict confidentiality.

**TABLE 1**

**How did you first become aware that there was something unusual occurring in the building?**

| | Tower 1 | Tower 2 |
|---|---|---|
| Heard or felt the explosion | 38% | 27% |
| Lost power or phone or noticed lights flicker | 5 | 11 |
| Saw or smelled smoke | 4 | 6 |
| Was told | 5 | 3 |
| Heard explosion and lost power | 27 | 30 |
| Heard explosion, lost power, and saw or smelled smoke | 6 | 5 |
| Heard explosion and saw or smelled smoke or dust | 11 | 7 |
| | | |
| Heard explosion, with or without another cue | 84% | 74% |
| Lost power, with or without another cue | 40% | 53% |

**TABLE 2**

**How serious did you believe the situation was at first?**

| | Tower 1 | Tower 2 |
|---|---|---|
| Not at all serious | 7% | 14% |
| Only slightly serious | 26 | 30 |
| Moderately serious | 39 | 38 |
| Extremely serious | 28 | 18 |

### Survey response

A total of 419 surveys were returned, and 406—or 25.4 percent of those sent out—were usable. The other 13 were returned by people who had not been in the complex on the day of the explosion because they were away on vacation, out on maternity leave, off-site for lunch, or out for another reason. The respondents ranged from 22 to 70 years old and included 199 women and 197 men.

The 406 usable survey responses included 229 occupants of Tower 1; 163 occupants of Tower 2; 7 occupants from the concourse levels; 1 each from the Vista Hotel, the World Financial Center, and 5 World Trade Center; and 4 who didn't report their locations. Four of the occupants of Tower 1 and six of the occupants of Tower 2 were at subgrade, concourse, or lobby levels in the buildings or in an elevator.

In the cover letter we mailed with the survey, we asked floor wardens who were not in the building at the time of the incident to pass the survey on to a colleague who had been present. Unfortunately, the survey didn't ask whether respondents were part of the fire safety team, but it seems clear from some of the responses that we did, in fact, receive surveys from people who were not.

Preliminary studies were based on the 382 occupants who were in the two towers—that is, those who were on floors 11 and above—who make up 23.9 percent of the surveys sent. There were 225 such respondents from Tower 1 and 157 from Tower 2. The following analyses do not include the 24 respondents who were on the concourse or lobby levels of the two towers or in other buildings in the complex. These returns have been set aside and will be analyzed later.

As shown in Figure 1, the bomb was placed closer to Tower 1 than Tower 2, and responses to many of the questions reflect this difference. The following analyses highlight results that we found statistically significant.

### How people became aware of the situation

Occupants were asked how they first became aware that something unusual was happening (see Table 1). Respondents mentioned hearing or feeling the explosion, losing lights or telephones, noticing smoke or dust, hearing sirens and alarms, getting information from others, and seeing other people evacuating the area.

Of the respondents in Tower 1, 84 percent reported that they were alerted by the explosion, with or without another cue, compared to 74 percent in Tower 2. Looking at the responses in another way, 53 percent of the respondents in Tower 2 reported that they became aware of the incident by a loss of power, with or without another cue, compared to 40 percent of the occupants of Tower 1. These responses are not mutually exclusive, since the explosion and loss of power were mentioned in combination by many of the respondents—35 percent in Tower 1 and 38 percent in Tower 2. In both of these analyses, the difference in response was significant.

Occupants were asked how they realized that what was occurring was a fire or an explosion. Responses were similar to those for the previous question, again either a single cue or a combination of cues, but most people mentioned noticing the explosion or smoke. Of the respondents in Tower 1, 69 percent reported that the explosion and smoke made them aware that a fire or an explosion had occurred, compared to 57 percent of the respondents in Tower 2. Again, we found this difference statistically significant.

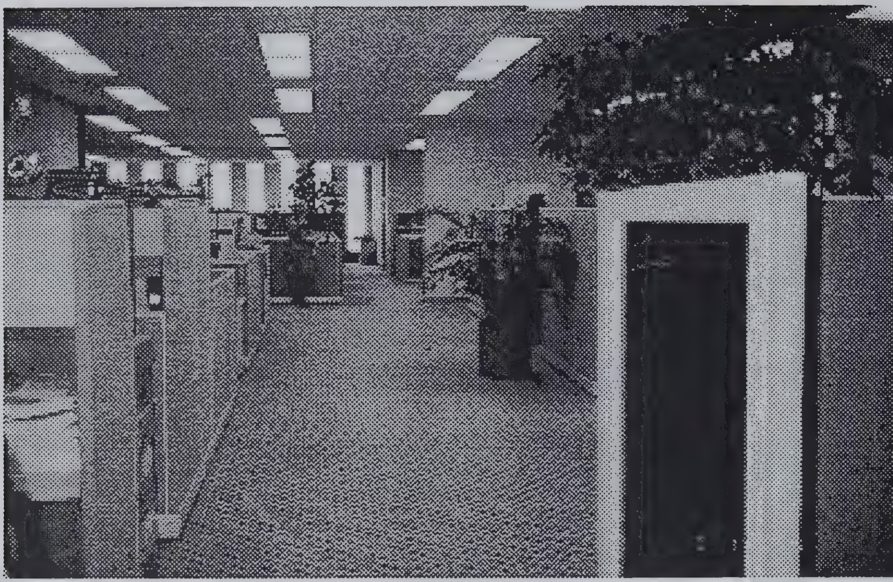
### Perception of seriousness

The occupants of Tower 1 were more likely to consider the incident very serious than the occupants of Tower 2, a statistically significant difference in perception (see Table 2). We tested for the possibility that differences in age or gender distribution between the two buildings might explain the discrepancy, and we found that neither influenced the results. Perception of severity didn't differ significantly by floor within the towers, either.

Within each tower, we checked responses to see if the perception of severity differed significantly depending on how people became aware of the situation. For Tower 1, respondents' perception of severity didn't differ significantly, whether they were alerted to the situation by the explosion or by the power loss. In contrast, Tower 2 respondents were significantly more likely to believe that the situation was extremely serious if they were alerted to it by the explosion rather than the power loss.

### Attempts to communicate

Respondents were asked if they called or tried to call the fire department (see


GUYLÈNE PROULX

**Each floor of the two towers measures approximately 1 acre. The floors are column-free to assure maximum layout flexibility.**

Table 3). Of the 222 respondents from Tower 1 who answered the question, 195—or 88 percent—didn't call the fire department, and 27 others—or 12 percent—called the fire department, the complex's emergency telephone number, or 911.

Of the 195 people from Tower 1 who didn't call, 21 gave reasons. Six said that the telephone system was down; six said that someone else called, would have called, or should have called; three said that the fire department already knew, or was already there; three said that they didn't know what was happening; two said they were in contact with Port Authority personnel, who knew; and one replied that he didn't call the authorities because his primary concern was for his fellow employees.

Fourteen of the 27 people in Tower 1 who called or tried to call the fire department commented. Seven said that the telephones were down, three said there was no answer, one said the fire department already knew, one said the alarm had already been pulled, one said there was no power at the box, and one said the emergency phone in the stairway was locked.

Of the 156 respondents in Tower 2 who answered the question, 123—or 79 percent—didn't call the fire department, and 33 others—or 21 percent—called the fire department or the emergency number.

Thirty-one of the 123 people in Tower 2 who didn't call gave reasons. Nine said the fire department already knew, eight said someone else called, five said the telephone system was down, three said they were in contact with Port Authority personnel, two said there was no telephone in the area, two said they didn't know what was happening, one said the alarm had been pulled, and one said staff had been instructed not to call.

Eleven of the 33 people in Tower 2 who called or tried to call the fire department commented. Four said there was no answer, four said the lines were busy, two said the telephones were down, and one said he wanted to let the fire department know where he and his fellow workers were.

Respondents were asked if they operated or tried to operate a manual pull station. Of the 222 respondents from Tower 1 who answered the question, 185—or 83 percent—didn't, and 37—or 17 percent—did.

Fourteen of the 185 people who didn't pull or attempt to pull a manual pull station, gave reasons. Five said someone else already had or should have, two said they didn't know where it was or couldn't see it, two said everyone already knew, and two others said they didn't know what was happening, one said there was no power and the pull station didn't work, one said the fire department was already there, and one said she just wanted to get out.

Fifteen of the 37 people who did or tried to operate the pull station said there was no power and it didn't work. Six said there was no answer, one pulled the alarm while trying to contact the Port Authority, one pulled the alarm shortly after smoke became visible, and one said she didn't expect it to work but no one else had tried.

Of the 152 respondents from Tower 2 who answered the question, 116—or 76 percent—didn't operate or attempt to operate a manual pull station, and 36—or 24 percent—did. Sixteen of the 116 who didn't gave reasons. Five said someone else already had or should have, five said the fire department was already there, two said there was no power and it didn't work, two said everyone already knew, one said she didn't know enough about what was happening to consider it, and one said that pulling the alarm would have caused a panic. Of those who operated or tried to operate the pull station, six said there was no power, five said there was no answer, and one said there was no tool to break the glass.

Respondents were asked if they called or tried to call the switchboard (see

**TABLE 3**

## Did you try to call anyone?

| Did you try to call the fire department? | Tower 1 | Tower 2 |
|---|---|---|
| No | 88% | 79% |
| Yes | 12 | 21 |
| **Did you try to pull the fire alarm?** | | |
| No | 83% | 76% |
| Yes | 17 | 24 |
| **Did you try to call the switchboard?** | | |
| No | 78% | 80% |
| Yes | 22 | 20 |
| **Did you try to call friends or relatives?** | | |
| No | 62% | 40% |
| Yes | 35 | 58 |

Table 3). Of the 222 respondents from Tower 1 who answered the question, 174—or 78 percent—didn't call the switchboard and 48 others—or 22 percent—called the switchboard, building services, or an emergency number.

Thirty-two of the 174 who didn't call gave reasons. Six said the phones were down, five said everyone knew about the situation, five said someone else called, four were at receptionists' stations, three just left, two didn't know what had happened, two said there was no switchboard to call, and one each reported that there was no telephone in the area, that he or she could not see the phone, that it was not the procedure, that they were waiting for instructions, and that the receptionist was out to lunch.

Sixteen of the 48 people who called or tried to call commented. Seven said the phones were out, four said there was no answer, two said the line was busy, one started to call but then realized that everyone was in the same predicament, one called the company switchboard outside the building to notify the operators that the power was off, and one said the receptionist was at lunch.

Of the 156 respondents from Tower 2 who answered the question, 124—or 80 percent—didn't call the switchboard, and 32 others—or 20 percent—called the switchboard, building services, or an emergency number. Thirty-six of the 124 who didn't call gave reasons. Ten said the phones were down, eight said someone else called, four said everyone knew about the situation, three were at receptionists' stations, three said there was no switchboard, two said there was no phone in the area, two said it was not the procedure, two didn't know what was happening, one said everyone was calling him, and one just left.

Six of the 32 respondents who called or tried to call said there was no answer, three said the phones were out, two said the line was busy, two said they didn't know what had happened, one found the security guard gone and the office locked, one tried to inform his company (off-site) of the problem, and one called and was told it was a transformer explosion.

**TABLE 4**

**Did you hear the fire alarm?**

| | Tower 1 | Tower 2 |
|---|---|---|
| No | 96% | 95% |
| Yes | 3 | 4 |
| Don't remember | 1 | 1 |

**TABLE 5**

**Did you move through smoke?**

| | Tower 1 | Tower 2 |
|---|---|---|
| Yes | 94% | 70% |
| No | 6 | 30 |

A higher percentage of respondents from Tower 2 called friends or family than from Tower 1, possibly because the fire cues in Tower 2 were less clear and long delays before evacuation gave people in Tower 2 more time to call (see Table 3). Of the 223 respondents from Tower 1 who answered the question, 138—or 61 percent—said they didn't call friends or family, 78 people—or 35 percent—said they did call, and another 7—or 3 percent—said they called after they left the building.

Sixty-two of the 78 who made calls called people outside the building, 11 called people inside the building, and 3 called people both inside and out.

Of the 156 respondents from Tower 2 who answered the question, 62—or 40 percent—didn't call friends or family, 91 people—or 58 percent—did call, and another 3—or 2 percent—said they called after they left the building. Seventy-nine of the 91 people who made calls called people outside the building, while 4 called people inside the building, and another 4 called people inside and out.

The survey asked respondents if they had heard the building fire alarms (see Table 4). Due to the severe damage to the emergency systems in the explosion, it is not surprising that 96 percent of all occupants in Tower 1 and 95 percent in Tower 2 said they didn't. Those who reported that they did hear an alarm may have been reporting local alarms, including door alarms. Most who reported a time when they heard the alarm gave times at, or almost immediately after, the explosion. Alarm durations ranged from 5 minutes to continuous.

### The evacuation

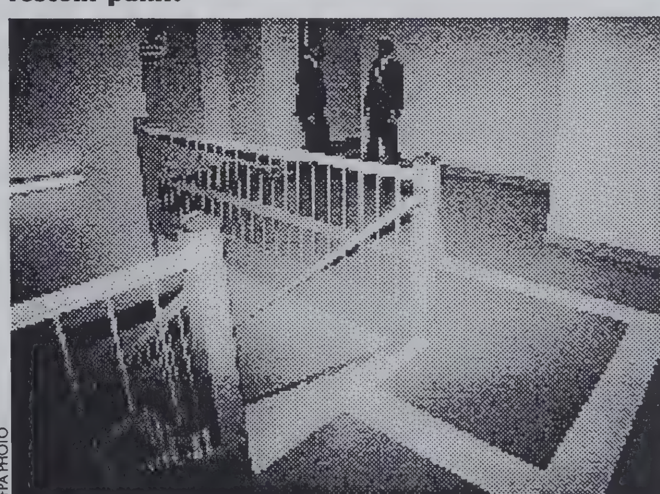
Respondents were asked if they moved through smoke, and if they had, how far they moved, how far could they see, and whether they turned back (see Table 5). The responses to the distance questions were subjective, and it often wasn't clear if the respondent was referring to horizontal travel distance on the office floor or to vertical distance in the stairs. For the question about how far they could see, the responses often had as much to do with the darkness as with the smoke.

Almost all the respondents in Tower 1—94 percent—and more than two-thirds of the respondents in Tower 2—70 percent—reported that they tried to move through smoke. This difference is statistically significant. Almost half of the

**At crossover points in some of the stairwells, evacuees walked into blank walls and were forced to feel their way along exit paths.**

GUYLÈNE PROULX

**Since the 1993 incident, exit paths in the stairwells have been marked for safety with phosphorescent paint.**



NFPA PHOTO

respondents in each tower who said they moved through smoke said they did so all the way out of the building. The proportion is probably even higher, since those who specified a distance or a number of floors may have been describing their entire travel path out of the building.

Of those who moved through smoke, more than three-quarters turned back. The difference between the two towers was not statistically significant. The most frequent reason given for turning back was the smoke. Other reasons included the crowd, locked doors, difficulty breathing, not being able to see, and being afraid.

Respondents were asked if they left or attempted to leave voluntarily, or without being told to do so. If they didn't leave voluntarily, they were asked why not. If they did, they were asked at what time they left (see Tables 6 and 7). Two-thirds of the respondents in Tower 1—66 percent— and almost half of the respondents in Tower 2—46 percent—left without being told to do so. An additional 8 percent in Tower 1 and 11 percent in Tower 2 tried to leave. The difference in responses between the two towers is statistically significant.

People who didn't leave voluntarily had several reasons for staying behind. Some said they were waiting for information or instructions, others felt it was better to wait or were told to wait, and still others said they didn't know there was a problem. Some occupants said they stayed behind to make sure that others left safely, and some people cited

**TABLE 6**

**Did you leave voluntarily?**

| | Tower 1 | | Tower 2 | | Total | |
|---|---|---|---|---|---|---|
| Yes, left | 147 | 65.9% | 71 | 45.5% | 218 | 57.5% |
| Yes, attempted to | 18 | 8.1 | 17 | 10.9 | 35 | 9.2 |
| No | 58 | 26.0 | 68 | 43.6 | 126 | 33.2 |
| **Total** | **223** | | **156** | | **379** | |

**TABLE 7**

**Reasons given for not leaving voluntarily**

| | Tower 1 | Tower 2 |
|---|---|---|
| Were waiting for information or instructions | 26 | 22 |
| Decided it was better to wait or were told to wait | 12 | 16 |
| Didn't know there was a problem | 6 | 10 |
| Were making sure others left | 9 | 5 |
| Had health problems | 3 | 3 |
| Decided there was too much smoke | 1 | 5 |
| Were waiting for better conditions | 1 | 3 |
| Were waiting for the fire department, as instructed | 0 | 1 |
| **Total** | **58** | **65** |

## The Worst Part Was the Fear of the Unknown

*by Valerie Hershfield*

When a terrorist bomb exploded beneath one of New York City's World Trade Center towers, thousands were trapped as smoke billowed up stairwells and into office spaces. In the long wait following the explosion and eventual evacuation, occupants were forced to cope with a situation for which they were not prepared.

According to Nelson Chanfrau, general manager of risk management for the Port Authority at the World Trade Center, a power outage complicated the evacuation of approximately 40,000 people who were anxious to escape from the towers.

"The blast knocked out all our fire protection systems," Chanfrau said. "We have six generators that provide emergency lighting for the complex. The blast severed the cooling systems for the generators. The generators ran for only about 12 minutes before they overheated and shut down."

The lights went out as hundreds of emergency vehicles congregated below. Although there was no power in the buildings, there were some working telephones and a few floors had battery-powered radios and walkie-talkies.

### Initial responses

Mary Ellen Kane, a corporate counselor for a company occupying three floors of one of the towers, met with many of the company's 273 building employees following the terrorist attack.

"These are people who sit at desks for a living," Kane said. "They don't expect to face life and death situations the way fire fighters or police officers do. Those professionals are trained in facing trauma. Our employees don't have the benefit of that training.

"The worst part of people's experience was their fear of the unknown. They all knew something terrible had happened, but the human mind goes into denial. People thought, 'this can't be real,' so they minimized what they were experiencing," Kane said.

"I was in a meeting with the staff," said Tom Hurlbut, division operations manager for Kemper National Insurance Companies. "I thought a plane had hit the building. Some thought it was a blown transformer. I looked up South Broadway, and the magnitude of the emergency services told us it was not a transformer."

Linda Kitowski, a support supervisor in one of the towers, remembers that the lights on her floor flickered and smoke began to fill the other side of the office.

"Even though I could see the smoke, my first thought was that Con Edison was doing some work on the power lines," Kitowski said.

"Another employee saw the explosion from across the street and thought they were making a movie," Kane said. "The tendency of the victims to deny that an emergency was unfolding conflicted with their next typical reaction, which was to switch to survival mode."

One woman called her family to assure them that "everything was okay, then followed the reassurance with a plea that

health reasons for staying. Other respondents said that there was too much smoke, they were waiting for better conditions, or they were waiting for the fire department, as instructed.

We compared the times the respondents said they became aware that something unusual had occurred with the times they gave for leaving. Then we compared the the times they gave for leaving with times they gave for becoming aware that there had been a fire or explosion (see Table 8).

For Tower 1, the times from awareness of the event to leaving the building ranged from 0 to 4 hours 5 minutes, with a mean—or average— time of 15.3 minutes and a median—or midpoint—time of 10 minutes. For Tower 2, the times ranged from 0 to 3 hours 27 minutes, with a mean time of 34.7 minutes and a median time of 15 minutes. This difference was statistically significant.

Similarly, for Tower 1, the times from awareness of a fire or explosion to leaving ranged from 0 to 4 hours 5 minutes, with a mean time of 11.3 minutes, and a median time of 5 minutes. For Tower 2, the times ranged from 0 to 3 hours 5 minutes, with a mean time of 25.4 minutes and a median time of 10 minutes. This difference was also statistically significant.

For those who tried to, but didn't, leave the building, the differences between the time they reported becoming aware of something unusual to the time they reported attempting to leave were statistically significant, as

**TABLE 8**

**Comparison of elapsed time between awareness of event, awareness of fire, and beginning evacuation**

| Delay times to leave the building | | Tower 1 | Tower 2 |
|---|---|---|---|
| *Time from awareness of event to leaving:* | | | |
| | Range | 0–4 hrs 5 min | 0–3 hrs 27 min |
| | Mean | 15.3 min | 34.7 min |
| | Median | 10 min | 15 min |
| *Time from awareness of fire or explosion to leaving:* | | | |
| | Range | 0–4 hrs 5 min | 0–3 hrs 5 min |
| | Mean | 11.3 min | 25.4 min |
| | Median | 5 min | 10 min |
| **Delay times for those who attempted to leave the building** | | | |
| *Time from awareness of event to attempt to leave:* | | | |
| | Range | 2–30 min | 10 min–4 hrs 14 min |
| | Mean | 8.9 min | 39.9 min |
| | Median | 8 min | 25 min |

her mother take care of her daughter if anything should happen to her."

"Clearly there was distress; some were crying," Hurlbut said. "Interestingly, I have never seen so much peer group support for one another. People consoled and comforted people who needed to be comforted. So much happened spontaneously. It was heavily skewed to the positive."

Kitowski said that when she began to hyperventilate as smoke filtered toward her side of the office, she was quickly comforted by a co-worker.

André Guibord, a tourist from Hull, Québec, was visiting the 107th-floor World Trade Center observation deck when the bomb exploded.

"We were completely out of touch," Guibord said. "We could see that all of the vital functions of the building had stopped functioning. Some officials had walkie-talkies, but we could only hear screams and garbled orders being given. There were a lot of screams."

Guibord reflected on his first impressions of the event. "We didn't panic, but we felt we were captive. We felt unsafe going down the stairs and elevators, of course. There was a lot of smoke coming up. Our biggest fear was asphyxiation." He said that even when the screaming stopped, "you could feel the tension."

### Switching to survival mode

Once everyone had registered that there was a crisis, their reactions depended upon their experience, according to Kane.

"In survival mode," Kane said, "all of the senses are heightened, and the adrenaline takes over."

"It was quite frightening at first because no one seemed to be in charge and everyone was looking for a leader," Guibord said. "I took the initiative and began to look for evacuation routes. I would not call myself a hero; we were just trying to save our skins.

"The smoke was beginning to hurt our eyes and breathing was difficult. Our greatest concern was fresh air," Guibord said. "At first we thought of breaking a window, but we had no way to break the safety glass. We looked for tools, but none were visible. Even the furniture was anchored, like at McDonalds. We would probably have been asphyxiated.

"There were a couple of people who seemed to be in authority, but no one had the key to the rooftop terrace door, which was locked. When we forced open the door to the roof, we saw there were actually three flights of stairs, which was a problem because there were a lot of elderly and physically and mentally handicapped people who needed help. There was one tour guide—I think his name was Tom—probably a retired person, who helped get everyone on the roof and later led everyone down 110 flights of stairs."

During Kane's 17 debriefing sessions with the bombing victims, she stressed that everyone is different and that no re-

well. For Tower 1, the times ranged from 2 to 30 minutes, with a mean time of 8.9 minutes and a median time of 8 minutes. For Tower 2, the times ranged from 10 minutes to 4 hours 14 minutes, with a mean time of 39.9 minutes and a median time of 25 minutes. These time differences were not statistically significant.

**TABLE 9**

**How long did it take you to leave the building?**

| | Tower 1 | Tower 2 |
|---|---|---|
| Less than 5 minutes | 1% | 1% |
| 5 to 30 minutes | 13 | 23 |
| 30 minutes to 1 hour | 26 | 47 |
| 1 to 3 hours | 52 | 28 |
| Over 3 hours | 9 | 1 |

Respondents were also asked how long it took them to leave the building (see Table 9). The purpose of this question was to collect evacuation times that could be used to test, or validate, evacuation models. Unfortunately, many of the respondents included time they spent resting or waiting in areas of refuge in their total travel time, but we were frequently able to extract the actual time spent leaving. Accordingly, more than 70 percent of the respondents in Tower 2 said they left the building in an hour or less, compared to 40 percent of the respondents in Tower 1. Fifty-two percent of the respondents in Tower 1 reported that it took them 1 to 3 hours to leave the building. A significantly higher percentage of respondents in Tower 2 evacuated in less time than respondents from Tower 1 because many delayed their evacuation until told to leave by the fire department, when conditions in the stairs had improved and more lighting was provided, making stairway travel easier and faster.

### Previous experience with fire alarms

Respondents were asked if they were aware of previous fire alarms in the building. If so, how many had there been in the past year? Did they evacuate the building or move to another floor during these alarms?

Many of the respondents who said they had been aware of fire alarms in the building specified that the alarms were fire drills. Others who simply checked off "yes" may have meant the same thing. Since the occupants' actions should have been the same whether the alarm was due to an actual incident or a drill, these responses can be looked at altogether (see Table 10).

Most of the respondents in both towers never left the building or the floor when alarms went off or drills were held. More than 90 percent of the respondents in Tower 2 never evacuated the building and never moved to another floor. In Tower 1, 79 percent of the respondents never moved to another floor, and 88 percent never evacuated. These results help explain why many respondents were unfamiliar with the stairs, in spite of the fact that most of the occupants who responded to the survey were fire wardens.

### What we can learn

Respondents reported that they were trained only to meet in the corridor and wait for instructions. According to one

## The Worst Part Was the Fear of the Unknown (continued)

action to a traumatic situation is wrong.

"Imaginations ran wild. Some people were afraid to open the doors to the stairwells, thinking bodies would be piled at the other side of the door," Kane said. Most of the people she interviewed told her that they believed they would not survive the incident.

"One of those trapped in the building was ashamed to admit that she became territorial when she saw a group of people approaching her part of the building after smoke had forced them out of their own area," Kane said. "She said, 'I realized that I didn't want them over here taking my air. These were my co-workers and friends, and I was willing to abandon their survival needs for my own.'"

"In traumatic situations, we don't always act as positively as we would like to think, but everyone involved was courageous," Kane said.

Some of the bravest people were the children who were visiting the observation deck when the bombing occurred.

"They were really well-behaved," Guibord said. "Their teachers had them sing songs and kept them stomping around, probably to keep them warm. It was snowing and quite windy and cold."

### Cooperation

Five hours later, many people were still just beginning to walk down as many as 110 flights of stairs to leave the building.

"When we walked down the stairs, we had to have one hand on the guy's shoulder in front of us," Guibord said. "It was terrifying walking in the dark. Some people were lighting matches and lighters. After 20 floors, we were confronted with a cement wall, for fire prevention, I guess. Someone lit a cigarette and created such a fuss. The smoke from the cigarette sent everyone into a panic. I was several flights above the smoker, and I could hear people screaming at him."

Kitowski echoed Guibord's reaction to their rescue.

"We were the last to be led out of the building," she said, "so most of the smoke had cleared by the time we left. The scariest part was finding our way down the stairs in the dark, since electricity had still not been turned on. The only guide I had was the shoulder of the person in front of me."

As frightened as the evacuees were, Chanfrau was impressed with their behavior.

"We had all the ingredients for panic and chaos, but it just didn't happen," he said. "The sense of order in an atmosphere of darkness and smoke was exceptional. No one was trampled, nor were there any incidents of that sort."

Because it was around noon, many of the employees were out for lunch. Nonetheless, they, too, experienced stress related to the incident. People who were not in the building said they felt guilty.

"They felt powerless," Kane said, "because they weren't there. One woman tried to run into the building after the bomb went off because she didn't want her friends to be scared."

person who answered the survey, "Fire wardens need better training; before the explosion, it was nonexistent, after, they had training sessions, which were helpful, but didn't use a hands-on approach (i.e., take us on a tour of different stairwells and ways to exit the building), which I think would be more useful. To this day, our floor is lacking a floor warden, who is responsible for the floor in the event of a fire."

**TABLE 10**

**During previous alarms did you . . .**

| | Tower 1 | | Tower 2 | |
|---|---|---|---|---|
| | Evacuate the building | Move to another floor | Evacuate the building | Move to another floor |
| Always | 6% | 5% | 2% | 1% |
| Usually | 2 | 6 | 0 | 3 |
| Sometimes | 4 | 11 | 6 | 4 |
| Never | 88 | 79 | 92 | 92 |

This lack of fire safety training might have caused a much bigger disaster. One respondent wrote, "I believe a bigger disaster was averted because most people were calm. With so many on the stairwell, many more could have been hurt if panicked people started to push or shove or cause others to be trampled. It was very important to keep a clear head."

Another respondent credited "a collective common sense and lack of panic for the fortunate absence of injuries."

Many people who participated in our study complained about their lack of emergency training and information. Many didn't understand the rationale behind basic fire safety protocols. One respondent wondered why they weren't allowed to break windows for fresh air, for example. Another reported that the air got better after people broke windows, "proving" that the rule against breaking windows was wrong.

Recent human behavior studies have shown that people will move through smoke, but this incident demonstrated that people will keep moving, even as conditions get worse. Many evacuees believed they were heading straight into the fire, but they kept going down, through increasingly thick smoke, without regard for the possible consequences of this behavior.

This incident also demonstrated that, in an emergency, floor wardens need enough information to be able to make safe decisions when the power shuts down and no information is forthcoming from authorities.

But training should not be limited to members of the fire safety team. Many fire wardens weren't even in their areas when the incident occurred. This is always a possibility, due not only to vacations, lunch breaks, and other regular leaves, but also to meetings that take place off-site or in other parts of the building.

All building occupants need some level of training or education if they are going to react safely to a fire in a high-rise. They should understand smoke movement in high-rises, the stack effect, and the dangers of falling glass to people below. If fire wardens are properly trained, occupants should look to them in fire emergencies. In some cases, fire wardens reported that they were overruled by their managers, even though the managers had no better or additional fire safety training.

People should also understand how emergency workers operate. Many who waited for hours on upper floors in Tower 2 complained about the time it took fire fighters to reach them. They were never told that if power is cut off, people on the upper floors of a high-rise, who are in no immediate danger, can expect fire fighters to take several hours to reach them.

Work on this project continues. There are additional variables that should be analyzed, including respondents' occupations—a variable found to be significant in some previous human behavior studies. In addition, responses from people on the same floor should be compared, particularly their descriptions of smoke and their perception of severity. Reported delay times require further evaluation, too, so that we can better estimate time before evacuation begins and what variables affect delays in evacuation.

This data could have great value for human behavior and evacuation modeling and will be detailed in future reports.

*Rita F. Fahy is manager of fire databases and systems in the NFPA's Fire Analysis and Research Division. Guylène Proulx, Ph.D., is manager of the Human Factors Project at the National Fire Laboratory of the National Research Council of Canada in Ottawa.*

1. Michael S. Isner and Thomas J. Klem, "Fire Investigation Report—World Trade Center Explosion and Fire, New York, New York, February 26, 1993," NFPA unpublished report.

**Lingering fears**

Last February saw the second anniversary of the terrorist attack. Kane said she expects lingering fears to stay with the victims indefinitely.

Guibord said he still has trouble riding elevators.

"I don't like to be in confined areas, even airplanes," he said. "It makes you realize how helpless you really are. There we were, fully able-bodied, amply able to do anything, and completely helpless."

Guibord still discusses the bombing with his family and friends. "Talking about it helps to get it out of your system, if you can," he said.

"This event addressed how vulnerable we are as people," Kane said. "If this had resulted from natural causes, it would not have been so intense."

The day Hurlbut was interviewed for this article, a bomb exploded on a New York City subway. He observed "a lot of anxiety" among employees who had experienced the bombing 2 years earlier.

"People were sent home," he said. "The attitude was: 'Not this again. I don't want to have to deal with this.'"

In addition to the stress associated with surviving this traumatic situation, victims expressed despair for the future.

Kitowski said she is "disgusted with the horrible condition of our society."

"The bombing brought me face to face with the fact that we don't need natural disasters to create havoc," Guibord said. "Who needs earthquakes when humans can destroy themselves so much more quickly?"

"[Since the bombing], there is more of a sense of 'I'm tired of this,'" Hurlbut said. He referred to the recent string of airplane crashes. "You can avoid taking an airplane, but a nut with a gun can open up on a commuter train or put a bomb in the place where you work. This is what makes it personal."

*Valerie Hershfield is a freelance reporter based in California.*

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The features of an enhanced model for egress from fires in non-residential occupancies is presented along with a users manual descrbing the use of the model. The enhancements to the model include analysis of locations of safety, smoke blockages, disabled occupants, and delays in egress. Comparisons with some available field measurements is presented. Further analysis of human behavior during a fire in the World Trade Center is presented. The analysis shows that there was a significant difference in perception of the severity of the fire between the two buildings of the World Trade Center. While previous human behavior studies have shown that people will move through smoke, this incident demonstrated that people will not only move through smoke, but also through worsening conditions. Implications for evacuation and training are discussed.

**KEY WORDS (MAXIMUM OF 9; 28 CHARACTERS AND SPACES EACH; SEPARATE WITH SEMICOLONS; ALPHABETIC ORDER; CAPITALIZE ONLY PROPER NAMES)**

computer simulation; egress; field tests; fire models; human behavior; training

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